

The Cloud Detection and Ultraviolet Monitoring Experiment, CLUE

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Abstract

In this paper we describe a new balloon instrument - CLUE - which is designed to monitor ultraviolet (uv) nightglow levels and determine cloud cover and cloud heights with a CO_2 slicing technique. The CO_2 slicing technique is based on the MODIS instrument on NASA's Aqua and Terra spacecraft. CLUE will provide higher spatial resolution (0.5 km) and correlations between the uv and the cloud cover.

1 Background

In this section we provide some background information on ultra-high-energy cosmic-rays, their detection by the air fluorescence technique, and the problems associated with clouds and their detection. In the next section we describe the CLUE instrument which is designed to monitor the uv fluorescence light from the atmosphere and the overlying clouds. In the final section we summarize.

1.1 UHE Cosmic-rays

For the purposes of this paper, ultra-high-energy cosmic-rays (UHECR) are defined as those with energies above 10^{18} eV (1 EeV). Their flux is very low, $10^{-12}/(m^2 - sr - sec)$, or less than 1 per square kilometer per century, as shown in Figure 1. Some have been seen at energies over 10^{20} eV, Figure 2. (AGASA [1], HiRES [2], Auger [3]) This is remarkable because at such extreme energies, these particles, if they are protons, must be coming from very local sources (<50 Mpc) or they would be cut-off by their interactions with the CMB - the GZK effect. Since we know of no such nearby sources, it may be that these particles are more exotic, and perhaps the signature of some new physics. Because of their rarity, very large detector areas are needed to observe them. The best vantage point is perhaps in fact from space.

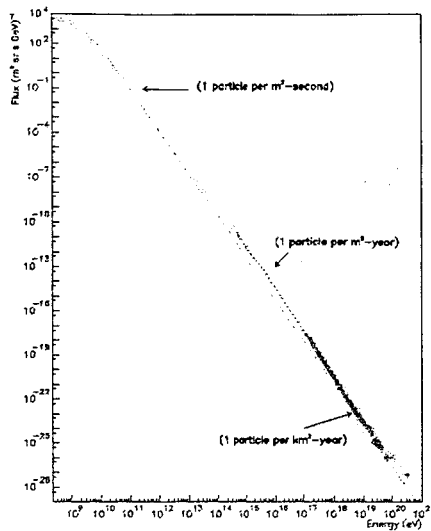


Figure 1: The all particle cosmic-ray spectrum, extending out to over 10^{20} eV. Particles above 10^{20} eV must be coming from nearby sources.

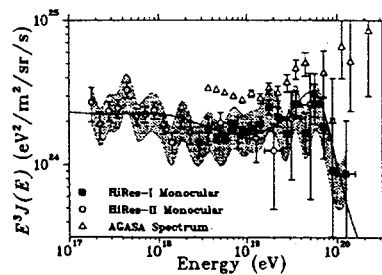


Figure 2: Event data above 10^{18} eV, from AGASA and HiRES. The two experiments don't exactly agree, but both show events above the GZK cutoff. [1] [2]

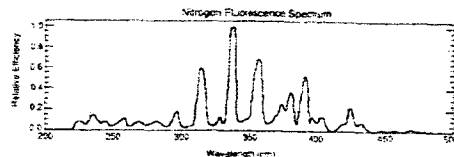


Figure 3: The spectrum of fluorescence light from nitrogen, between 300 and 400 nm. Above 330nm there are three regions of lines.

1.2 Air showers and Fluorescence

To observe UHECRs from space one would rely on the fluorescence light from the atmosphere as the particle enters and creates an air shower. (references to EUSO and OWL here) Once the particle interacts, it creates pions, muons, electrons, and photons, which themselves interact, building up the number of particles travelling through the atmosphere (an air shower). As the shower traverses the atmosphere it continually excites the nitrogen, causing it to fluoresce between 330 and 396 nm (the near ultra-violet). The spectrum of this light is shown in Figure 3. From observations of this light one can determine the height of the primary interaction, and the primary energy (since the amount of fluorescence light per meter per eV is known), and from the geometry, the direction in which the primary was travelling. This is the technique used by both the Fly's Eye and HiRES experiments at the Dugway Proving Grounds in Utah.

1.3 The cloud problem

Observing flashes of uv light from an orbiting spacecraft is in principal easy, and yet there are complications. The biggest one is cloud cover. In order to reconstruct the particle track and accurately determine the primary particle energy, one must image a long track, hopefully including the portion around the "shower max" (where the number of shower particles reaches its peak). These tracks are typically tens of kilometers long, and extend down low in the atmosphere, 5 - 10 km up from the surface. As you can then imagine (and see illustrated in Figure 4) any overlying clouds above or around the particle track will interfere with the measurement. If the amount and type of cloud cover is known, corrections can be applied. But the key is that one must know what the cloud structure and distribution is in real time, at your location. Specifically, clouds can absorb and re-scatter the uv fluorescence light and can block the viewing of shower max. The total amount of cloud cover at any given time directly affects the instantaneous aperture of the observing instrument, which must be known in order to compute absolute particle fluxes. The distribution of clouds taken from the NASA Aqua spacecraft is shown in Figure 5. From this one can see that it is impossible from any orbit to avoid clouds. Only a small band of latitudes in the Southern Hemisphere are relatively cloud free. Over most of the remaining latitudes, clouds are visible more than 20% of the time, and maybe as much as 60 % in some regions. Hence the importance of CLUE.

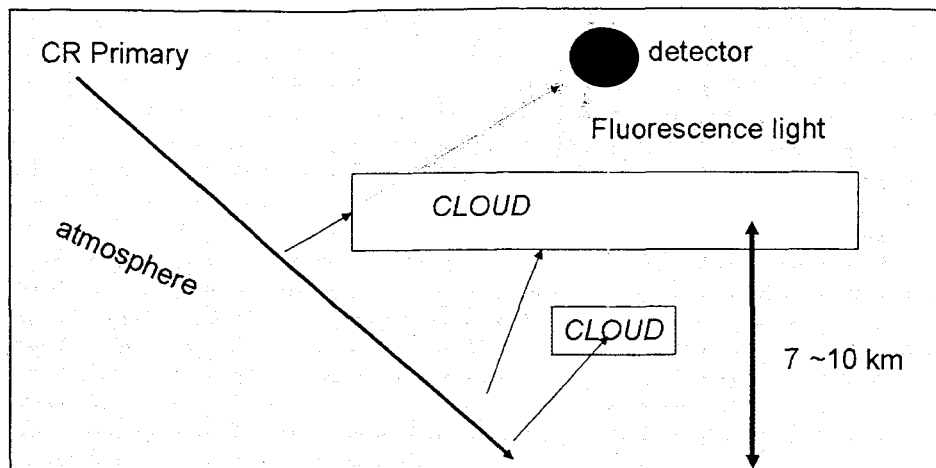


Figure 4: Illustration of the problems caused by clouds when trying to image a particle track from space. When light arrives at the detector, it is important to know what the attenuation - if any - due to clouds was.

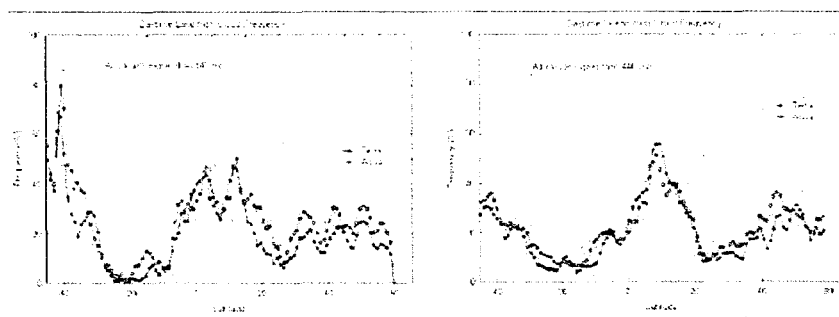


Figure 5: Cloud distribution and frequency data from the AQUA spacecraft averaged over one month - January 2003, for purposes of illustration. Clouds are very infrequent around the Tropic of Capricorn in the Southern Hemisphere, but very prevalent elsewhere.

1.4 CO_2 Slicing

Clouds come in a large variety of types, as everyone knows. From optically thick cumulus to wispy thin cirrus and form at altitudes up to 75 kfeet (22 km). Identifying clouds is not always as easy as one would imagine, especially from space. Typically there are three techniques by which clouds have been identified in the past: by measuring cloud top temperatures (looking at temperature thresholds) and by looking for spatial and / or temporal coherence. A newer technique is now used (e.g. by the MODIS instruments on NASA's Aqua and Terra spacecraft), called " CO_2 slicing". CO_2 slicing can not only identify the presence of clouds, but can also determine accurately their altitude - a major advantage. For convenience, I refer to it as "cloud slicing". Cloud slicing relies on the fact that in the IR (10 - 14 microns), CO_2 absorption increases (monotonically) with wavelength. This means, for example, that the longer wavelengths (14 microns) are sensitive only to the highest cloud tops, while at 10 - 11 microns, sees down to the surface. By measuring IR radiance in several adjacent IR bands and taking the differences, $\Delta T_{i,j}$ one can determine the cloud and cloud altitude distributions.

The full description of the cloud slicing technique is given in Sokolsky and Krizmanic [4], and Ackerman et al. [5] We summarize here. Let $R(\lambda)$ be the observed radiance at wavelength λ . R has contributions from four terms: the surface below, the clouds below, the atmosphere below, and the atmosphere above. If f is the fraction of the observed area that is covered with clouds, then the total observed radiance is:

$$R(\lambda) = R_{surface}(\lambda, T)(1 - f) + fR_{cloud}(\lambda, T_c) + R_{below}(1 - f) + R_{above}$$

and if $f = 0$ (for clear skies):

$$R(\lambda) = R_{surface}(\lambda, T) + R_{below} + R_{above}$$

Subtracting the clear sky observation from the cloudy sky one yields:

$$\Delta R = -fR_{surface}(\lambda, T_S) + fR_{cloud}(\lambda, T_C - fR_{below}$$

Now the radiance R is equal to the emitted radiation (given by the Plank function, $B(\lambda, T)$) times the atmospheric absorption, $\tau(\lambda, P)$ for the surface and / or the clouds and by the integral

$$R_{below} = \int_{P_s}^{P_c} B(\lambda, T(P)) (d\tau/dP) dP$$

for the lower atmosphere, where $T(P)$ is the temperature profile of the atmosphere. An integration by parts yields:

$$\Delta R = f \int_{P_s}^{P_c} \tau(\lambda, P) (dB(\lambda, T(P)) / dP) dP$$

If one makes measurements at two nearby wavelengths, λ_1 and λ_2 , then the ratio $\Delta R(\lambda_1) / \Delta R(\lambda_2)$ is independent of f and depends only on P_c .

The technique is then, to use the measured ratio $\Delta R(\lambda_1) / \Delta R(\lambda_2)$, iterate P_c until the integrals on the RHS match the data. Once you have the correct P_c , that determines the cloud top altitude. You can use this value of P_c and the expression for ΔR to find f , the cloud fraction in the observation area. Aperture calculations for flux determinations require knowledge of f .

2 CLUE Instrument

We are proposing to build and fly a balloon instrument to measure cloud cover and correlate it with UV observations. The basic design is based upon our NIGHTGLOW instrument [6] - augmented with an array of infrared (IR) sensors. The instrument will consist of three main detector systems: an active LIDAR, a suite of three uv monitoring telescopes to determine the fluorescence background, and an array of IR sensors. These will each be described briefly below. An overview of the instrument is shown in Figure 6.

2.1 LIDAR System

The LIDAR system is used to measure the optical depths and altitudes of clouds, in a small area directly below the payload. The system consists of a 337 nm, 10mJoule/pulse, N2 pulsed laser, a 26 inch (66 cm) diameter primary mirror with an 8 inch (20.3 cm) diameter secondary, and an XP3037FL PMT with a narrow bandpass filter ($\pm 10nm$). The light from the laser is directed downward where it reflects back from the ice particles in whatever clouds it encounters. The reflected signal is captured, detected by the PMT, and the waveform is digitized by a Chase Scientific 5 MHz sampling ADC. From the digitized waveform we can determine the cloud optical depth (from the amplitude of the reflected pulse) and its altitude (from the time structure of the waveform). This system has been successfully employed on the NIGHTGLOW balloon instrument and is shown in Figure 7.

2.2 UV telescopes

The three uv monitoring telescopes are mounted side-by-side on the bottom platform, viewing in the nadir direction. Each telescope is optimized for a particular group of fluorescence lines, 330 - 340 nm, 350 - 360 nm, and 380 - 390 nm. The atmospheric nitrogen fluorescence is strongest in these three bands. Each telescope has a 14

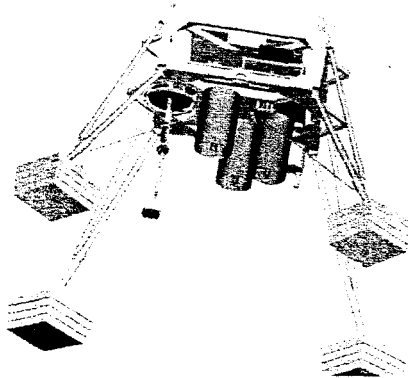


Figure 6: Schematic of the CLUE instrument. The design is based on the NIGHT-GLOW design. The LIDAR, UV telescopes, and IR sensor array are all mounted underneath a deck, looking downward. The electronics is on top of the deck.

inch primary mirror which focuses directly onto a pair of PMTs, through a beam splitter and a UV filter. One PMT sees only the UV component, the other sees the entire spectrum for reference. The telescope shrouds are made of carbon-fiber epoxy material. The readout is done by a Burr-Brown ACF 2101 integrator chip. A single telescope is shown in Figure 8.

2.3 IR array

The CO_2 slicing technique described above is done on-board by an array of IR sensors, as shown in Figure 9. These sensors are filtered (using interference filters) to cover the same wavelengths used by the MODIS instruments, and given in Table 1. We are planning to use the OMEGA Scientific sensor (model OS65-V-R2-1), which has a range down to $-57^\circ C$. These are lightweight and easy to use, being readout via an RS-232 connection. Given the temperature vs. pressure atmospheric profile and the atmospheric absorption at wavelength λ as a function of pressure, the CO_2 slicing technique described above can be applied. The cloud top pressure P_c must be chosen to match the data at all six wavelengths for consistency, from which the fraction of the pixel (sky) obscured by clouds (f) is obtained.

3 Conclusions

This paper describes the *CLUE* instrument and its goals. *CLUE* is based upon the NIGHTGLOW instrument but with extended capabilities to perform CO_2 slicing. It is designed as a balloon payload for moderate duration flights. *CLUE* will be able

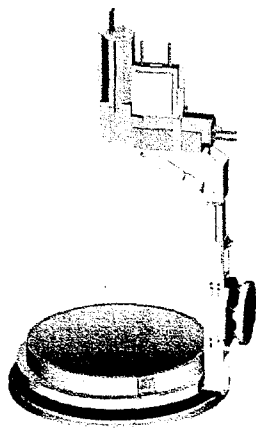


Figure 7: Schematic of the CLUE instrument uv telescope (one of three). Two PMTs are housed in a sealed assembly at the focus of the 14 inch diameter primary mirror. One PMT sees only a single uv band, the other sees the full spectrum for reference.

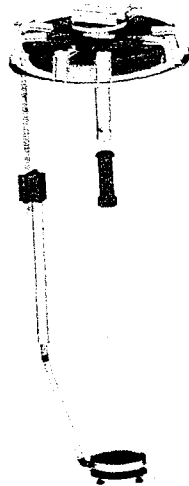


Figure 8: Schematic of the CLUE instrument lidar system. The laser light (from a separate module - not shown) reflects back from underlying clouds and is collected by the 26 inch primary mirror, and focused onto a PMT from an 8 inch secondary. The secondary is mounted on an adjustable arm for ground operations.

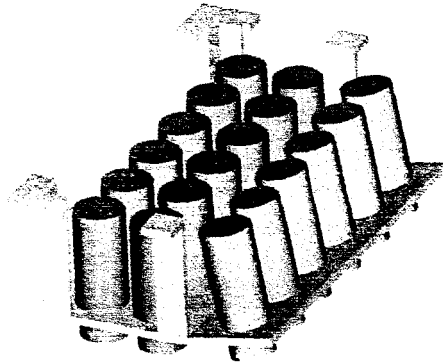


Figure 9: The array of IR sensors as mounted under the electronics deck. The 2x6 array covers six wavelength bands each with two sensors for redundancy. The third set of six sensors is angled to view an off-axis reference area.

Table 1: Summary of IR Bands

IR Band (λ)	Bandwidth ($\delta\lambda$)
(microns)	(nm)
11	500
12	500
13.3	300
13.6	300
13.9	300
14.2	300

to: determine cloud heights and optical depths directly from LIDAR measurements, determine cloud heights from CO_2 slicing in the IR, and compare and correlate the two techniques. In addition, CLUE will be able to measure the near UV background in three distinct wavelength regimes of importance to air fluorescence measurements of high-energy cosmic-rays. Finally, CLUE will be able to correlate the UV and the cloud cover measurements.

References

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